IMPROVING INFILTRATION CONTROL TECHNIQUES IN LOW INCOME WEATHERIZATION

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ABSTRACT

Infiltration control technologies have been the most frequently applied energy conservation measure in low-income weatherization programs. The common approach has typically utilized weatherstripping and exterior caulking in conjunction with window repair.

In an effort to reduce costs while increasing effectiveness, a different approach to infiltration control was tested. A blower door was used to locate actual leakage sites. Time and level of effort guidelines were developed based on pre-retrofit air changes at 50 pascals depressurization (ACH50) to assist the weatherization crew in making work judgements. Two different methods for incorporating blower doors into the weatherization program were tested.

One group of 18 houses received infiltration control work only, with an average expenditure of $106 in labor and materials, about 19% of the amount typically spent in Wisconsin. The other group of 31 houses received an average of $147 in infiltration related work in addition to other weatherization measures. Air change rates (ACH50) in both of the groups were reduced by about 15%, with 31% of the houses receiving no specific infiltration control work. The low-income houses in the study had lower pre-retrofit air change rates than anticipated (9.6 ACH50 average).

The results indicated that use of a blower door and related field management procedures could lead to increased predictability of the effectiveness of infiltration control and that costs of infiltration work could be reduced while still significantly reducing air leakage in the house.

1.0 INTRODUCTION

Infiltration reduction has long played a substantial part in the Department of Energy's Low-Income Weatherization Assistance Program. Historically, a large fraction of retrofit expenditures has gone to caulking (generally exterior) and weatherstripping doors and windows. In the past few years several concerns about conventional infiltration reduction work have surfaced. One concern is that the energy savings do not appear to be as large as expected. Another concern is that substantial infiltration control work is often performed on houses which already have quite low infiltration rates, sometimes evidenced by moisture problems. Finally there is the perception that expensive but relatively unimportant infiltration retrofits (e.g. window weatherstripping) are performed while major leaks go unattended in the same house.

WECC raised these problems in a previous study (Hewitt, 1984). That study determined that Wisconsin's Low-Income Weatherization Program spent 35% of retrofit dollars on infiltration control ($570 average), and an additional 8% on carpentry work related to windows and doors. Energy savings from Wisconsin's program were on the order of 8%-10%, while total expenditures, including administrative costs, were over $2200 per house (labor and materials totaled about $1630). A revisit to houses weatherized in the previous year showed that the majority of houses had major infiltration problems remaining, typically in wall and ceiling areas. The primary technical recommendation to improve energy savings was to change the selection of weatherization measures, including use of blower doors to locate infiltration areas and de-emphasizing weatherstripping. A second Wisconsin based study (Kanarek, 1985) of 50 low-income houses found no significant difference in air change rates before and after installation of typical weatherization measures including infiltration control measures.

Weatherization programs in many states follow a pattern similar to Wisconsin's. Weatherization crews typically spend large amounts of time on minor infiltration problems, especially window areas. This reflects the simple prescriptive nature of their technical guidelines and the lack of a feedback mechanism to show when infiltration control work is effective.

This research is part of a larger project to develop an integrated building shell/mechanical audit system involving the Alliance to Save Energy, Oak Ridge National Laboratory, the State of Wisconsin's Department of Health and Social Services, and the U. S. Department of Energy's Office of Buildings and

Community Systems and Office of Weatherization Assistance. Local low-income weatherization providers and three Wisconsin utilities are also assisting the project.

2.0 STUDY DESIGN

As part of a larger study on improved audit systems (McCold, 1986), WECC reviewed possible approaches to infiltration control. The purposes of the infiltration study design were to: better quantify estimates of the energy savings attributable to infiltration control; determine if a blower door based approach to infiltration could be more effective and efficient than the current approach of local Low-Income Weatherization Programs; and review the problems and benefits of incorporating blower doors in Low-Income Weatherization Programs.

Two approaches to blower door guided infiltration control were tested, one within the audit system and the second as a single retrofit. The same research design was used for both groups.

Houses were all low-income occupied, single family structures. All houses were heated with natural gas with either no supplemental heat or limited electrical supplemental heat (e.g. bathroom heater). Mobile homes were excluded from the study. The houses were spread across five counties in south central Wisconsin, a 7700 degree day climate. Houses were randomly assigned to one of three groups; an infiltration control only group (blower door group), a group that received a variety of retrofits as selected by an audit system (audit group), and a no-treatment control group.

Houses were selected in the fall of 1985. Energy usage data consisting of gas usage, electrical usage and furnace run time were collected on a weekly basis. The furnace was calibrated to determine consumption per hour of on time.

All retrofits to the houses were scheduled for the third and forth weeks of January, the mid-point of the heating season. Weekly data readings continued through the first week of May. In this manner the effectiveness of the retrofits could be judged relative to different temperature regimes but still within a shorter period of time than the traditional heating season to heating season study. The control group is used to correct for seasonal variations as well as its more typical functions.

Initially each of the three groups (blower door, audit and control) were scheduled to have 40 houses. However, by the study deadline only 108 qualified houses had been located. As the primary function of the larger study was to determine the effectiveness of the audit, the audit group and control group received their full complement of 40 houses while the blower door group received the remaining 28 houses. Further attrition resulted in 34 houses in the audit group (31 with complete infiltration data) and 18 houses in the blower door group.

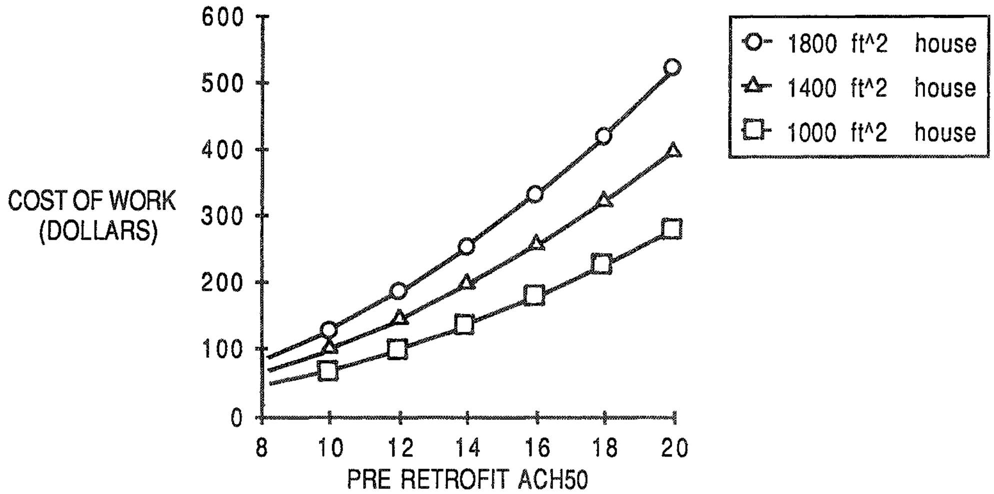
A key element of the study was that all retrofit work was completed by the weatherization crews of local agencies. WECC provided some additional training to the crew members and auditors to familiarize them with the special procedures to be followed.

Blower doors were developed as a research tool in the mid-1970s by Princeton University. The field procedures and the calculations used to estimate costs and savings in this study were developed by WECC. These procedures and calculations are based on WECC's previous experience with blower doors and the experiences of several private contractors and a utility that commonly use blower doors.

2.1 Blower Door Group

Weatherization crews were sent to the blower door houses with no prior knowledge of the house condition. The crews were equiped with a calibrated blower door and carried a wide variety of infiltration control materials in their truck. A WECC staff member went to the first house with each crew to demonstrate the procedure and answer questions. In all cases at least one member of the crew had had previous, though limited, exposure to blower door usage.

The blower door was used to determine air changes at 50 pascals of depressurization (ACH50). Based on this reading the crew was given two guidelines to estimate the level of effort to put into the house. Both guidelines were primarily based on the leakiness of the house. Houses that were tighter than the predetermined standard of 8 ACH50 were to receive little or no work to avoid potential moisture and/or indoor air pollution problems. The first guideline estimated an amount of money to spend on infiltration control (Figure 1). To determine the number of person-hours to spend on the job the crew divided the recommended expenditure level by the assumed rate of $20/person-hour for labor and materials.



Formula: (Pre retrofit ACH50)^2 * House ft^2 / 1400 = Recommended expenditure level, labor and materials

Figure 1. Recommended Expenditure Levels, Guideline 1.

The second guideline for infiltration control work set an ACH50 reduction target that could be tested as work progressed (Table I). The reduction target was used more as an expectation of the level of reduction, rather than an absolute goal. In cases where the ACH50 reduction target had been reached and there were still large, relatively easy leaks to seal, the crew was told to reduce the ACH50 level further as long as they remained close to the recommended expenditure level.

Table I. ACH50 Reduction Targets, Guideline 2.

Pre-Retrofit ACH50	ACH50 Reduction Target
8 or less	Seal leaks that affect comfort
8 to 10	Reduce ACH50 by 1
10 to 12	Reduce ACH50 by 2
13 to 15	Reduce ACH50 by 3
16 to 18	Reduce ACH50 by 4
18 or greater	Reduce ACH50 by 5

The crew was to strike a balance between the two guidelines by working on reducing the ACH50 rate until they either reached (or surpassed) the reduction target or spent the recommended amount of money. The decisions on what specific leakage areas to address were left up to the crew. The general guidance from WECC was to "Fix big leaks; Fix cheap leaks." Weatherstripping windows was discouraged in favor of finding larger leakage areas with the help of the blower door. Use of the door made leakage areas obvious and easy to locate.

2.2 Audit Group

The audit group received a combination of building shell and mechanical system retrofits as determined by an audit. Infiltration work was one of the options considered.

These houses were first visited by an auditor to collect the data needed to determine the appropriate retrofit combination. For infiltration purposes, the auditor determined the air changes at 50 pascals and prepared a prioritized list of major and minor infiltration areas on the audit form. The infiltration areas were located with the assistance of the blower door.

WECC analyzed the data collected by the auditor and determined a benefit/cost ratio for each weatherization option based on estimated costs and savings. The retrofits with the best benefit/cost ratios were performed on the houses. For infiltration, a determination was first made regarding whether any infiltration work would be completed based on the estimated benefits and costs. If infiltration work was selected for the house, a cost parameter was specified.

The formulas used to estimate these costs and savings were derived from those used in the blower door group. In the audit group, the recommended expenditure levels were reduced to one-half that of the infiltration group, with the assumption that 75% of the infiltration reduction could be achieved for this reduced level of effort. A savings fraction was calculated using Equation (1), developed by WECC. The annual savings were estimated from Equation (2), a modified ASHRAE calculation using ACH50 readings, the house volume, and heating degree days corrected by C_d (HDD * C_d(.6)=4638 Madison).

$$\text{Savings Fraction (SF)} = [(2*\text{ACH50})-10]/100*.75 \qquad (1)$$

$$\text{Annual Savings (MMBtu)} = \text{SF}*(\text{ACH50}/20)(\text{Volume}*\text{HDD}*24*.018)/10^6 \qquad (2)$$

The weatherization crew received the cost parameters and the list of major and minor infiltration areas as determined by the auditor. The crew determined which infiltration control measures to install based on the prioritized list prepared by the auditor with the general guidance of completing low cost, highly effective measures first. The crew relied on the information from the auditor who had visited the house previously instead of using a blower door to guide their work.

WECC performed follow up inspections on all of the houses in the audit group. Post-retrofit air change rates (ACH50) were measured during the inspection.

3.0 DISCUSSION OF RESULTS

3.1 Field Experience

Observations from the field indicated that some weatherization crews had difficulties in breaking their old infiltration control habits (Figures 2 & 3). They frequently overspent the expenditure guidelines, especially on houses that had low leakage rates where little energy savings from infiltration control could be expected. This effect was much more pronounced in the audit group, where the crew did not have the blower door with them. For the 31 houses in the audit group WECC recommended an average expenditure of $52 for infiltration control while actual costs of the work averaged $147 (averages of $115 recommended and $270 actual for those houses where infiltration reduction was specified). The actual costs were driven primarily by several extremely large amounts of money spent on houses that were already quite tight. For example, for one house tested at less than 7 ACH50 WECC recommended spending only $15 but the crew disregarded the guideline and managed to spend $486. For a moderately tight house (10.2 ACH50) WECC recommended an expenditure of $53 but the crew spent $321. It is unlikely that these higher expenditure levels resulted in cost effective conservation - especially relative to other weatherization options.

In the blower door group, expenditures were reasonably close to the levels suggested by WECC except for a few houses (Figure 2). As the pre-retrofit ACH50 level increased, so did the expenditures. The recommended expenditure levels derived from guideline 1 for all of the 18 houses averaged $77 per house and the crews spent an average of $106 including labor and materials ($97 guideline and $124 expenditure averages for the 14 houses where work was performed). A portion of this overexpenditure is obviously due to the cost of performing the blower door tests on tight houses where there is no infiltration reduction work, and therefore no expenditure, recommended. The reported costs for setting up the door and performing the initial test ranged from $13 to $68.

Both the audit and blower door groups contained houses that were so tight that no additional tightening was needed or desirable due to potential moisture or indoor air pollution problems. Most of these houses had initial air change rates of less than 7 ACH50. In the infiltration group no work was done on 4 of 18 houses. In the audit group, no infiltration work was completed on 11 of 31 houses (based on cost/benefit criteria as well as potential moisture problems). Work was actually recommended on only 14 of the 31 audit group houses. However, on 5 houses the auditor or crew disregarded the guidelines and infiltration control work was performed as a repair item.

3.2 Effectiveness of Effort

Table II summarizes the costs of achieving various levels of air change reduction (ACH50). The average ACH50 level in the blower door group was reduced by 15.4%, and by 16.8% for the 14 houses where infiltration control work was recommended. Using equation (2), the annual savings from this level of reduction can be estimated at 2.1 MMBtu ($17 at $8/MMBtu), with a simple payback of 6.2 years.

Table II. Average Characteristics of the Houses by Study Group

Group	# of Houses	Area Ft^2	ACH50 Pre	ACH50 Post	Expenditures Rec.	Expenditures Actual
Blower Door						
Total Group	18	1160	8.29	7.01	$77	$106
Work Rec.	14	1189	9.78	8.14	$97	$124
Audit Group						
Total Group	31	1315	10.41	8.77	$52	$147
Work Perf.	19	1268	11.84	9.48	$85	$240
Work Rec.	14	1192	13.89	10.52	$115	$270

The average ACH50 level in the audit group was reduced by 15.8%. For the 14 houses where infiltration work was recommended the ACH50 level was reduced by 24.3%. It should be noted that all of the audit group houses had additional weatherization work completed, ranging from wall or ceiling insulation to furnace retrofits or replacements. It is assumed that part of the audit group's ACH50 reduction can be attributed to these other retrofits, but this portion could not be quantified in this study.

Some of the audit group houses had increases rather than reductions in the ACH50 rate. Since the pre and post blower door tests on the audit group were performed at different times (sometimes 6 months apart), differences in the house set-up (storms on/off, window air conditioner in/out, etc.) or in the testing procedure could have contributed to some variance in readings. The inspectors observed these types of changes in 7 houses. For the remaining 24 of the 31 audit group houses the ACH50 level was reduced by 23.2% (11.31 to 8.70 ACH50).

Figures 4 through 9 provide a graphic analysis of the two approaches to infiltration control and how the crews responded.

As initial house leakiness increased, so did the ability of the crews to reduce that leakiness (see Figures 4 and 5). Thus knowing the initial air change rate (ACH50) of the house should help determine a level of effort guideline for reducing infiltration, as well as to help predict the possible energy savings attributable to infiltration control.

In the blower door group the expenditures were higher where greater ACH50 reduction was accomplished (Figure 6). This indicates that money must be spent to reduce infiltration: you just have to know where to spend it and when to stop. Figure 7 shows that while there was significant ACH50 reduction in many of the audit group houses, there was no clear relationship between expenditures to reduce infiltration and the actual ACH50 reduction. It appears that some of the ACH50 reduction was due to the other retrofits that were performed on these houses. This is especially true for those homes on the Y-axis where no specific infiltration work was performed.

In Figures 8 and 9 an air change (ACH50) reduction efficiency measure is represented. These graphs show a clear trend in an increase in efficiency, measured as the amount of air infiltration reduction produced per $100 expended, as initial leakiness of the house increases. The houses at the top of Figure 9 had no specific infiltration control expenditure even though five of them had reductions in the ACH50 rate. WECC estimates that for an average house in Wisconsin's climate, a reasonable ACH50 reduction target would be to reduce the ACH50 by 1 for every $100 expended. The graph of the blower door group indicates that this was possible for all houses (except one) starting above 8 ACH 50 and tends to improve for leakier houses.

It appears that use of the outlined approach for the blower door group resulted in increased predictability of results and an efficient approach to reducing infiltration. Having the blower door on site while the infiltration control work was being performed, and implementing the associated procedures and guidelines used in the blower door group resulted in a more cost effective reduction of the air change levels. It should be noted, however, that the small size of the final blower door group makes well defined conclusions difficult.

4.0 RECOMMENDATIONS AND CONCLUSIONS

Despite the small final sample size, several conclusions are possible.

1. Many houses, even low-income houses, need little or no infiltration control work. By not performing infiltration work on these houses more resources could be freed for other, more cost-effective weatherization work.

2. The measurement of initial air tightness appears to be useful in determining the amount of infiltration work that can be efficiently performed and the amount of infiltration reduction that can be achieved. Measured ACH50 rates can help a crew to determine which houses to work on, and how much work to do on each house.

3. Weatherization crews appear to be most responsive to using a blower door on site, as opposed to relying on an auditor's written judgement of how much work to do and which work to do.

4. Proper training and field experience are necessary for the successful implementation of a blower door guided approach to infiltration control. The guidelines and procedures developed by WECC can assist in that implementation. From a management perspective it may be useful to have weatherization crews that specialize in infiltration control work, or to combine the audit with infiltration control work (i.e. create a crew of two: an auditor and a weatherization worker).

5. It appears that WECC's formulas conservatively estimated the amount of air infiltration work that could be performed in an efficient manner. In some houses the crews were able to achieve greater air tightness reduction

efficiency levels than WECC estimated, especially for those houses in the blower door group having pre-retrofit air change rates between 5 and 10 ACH50.

6. The dollar amounts spent on infiltration control in this study (labor and materials) are substantially below the amounts spent in Wisconsin's Low-Income Weatherization Program; approximately 1/5 to 1/4 the current expenditure level. For this level of expenditure the average ACH50 reduction in the blower door group was 15.4%. These results indicate that use of a blower door guided approach could lead to increased effectiveness of infiltration control and that costs could be reduced while still significantly reducing air leakage in the house.

Wisconsin's housing stock is likely to be substantially tighter than the national average, a vernacular reponse to the climate. Thus approaches in different areas need to factor in climate, house size and leakiness to determine the appropriate level of air infiltration control work.

A direct test of a method similar to the one presented here compared to a more traditional infiltration control approach would be useful. Indications are that the blower door assisted method can achieve similar or better energy savings than the more traditional approaches to infiltration control for less effort.

REFERENCES

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FIGURE 2

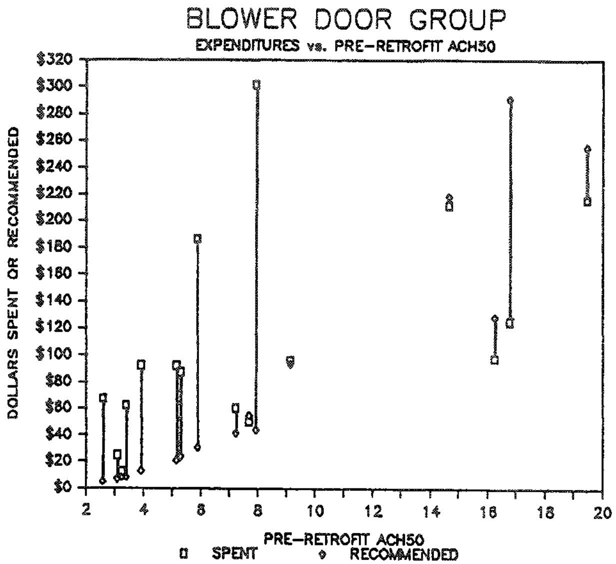
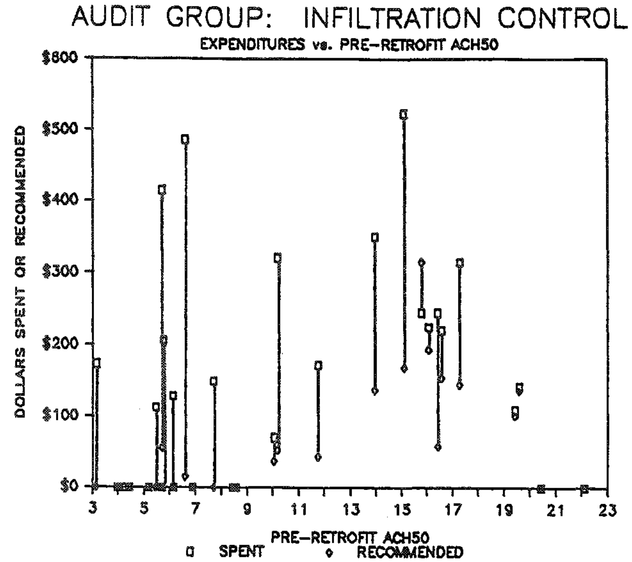


FIGURE 3



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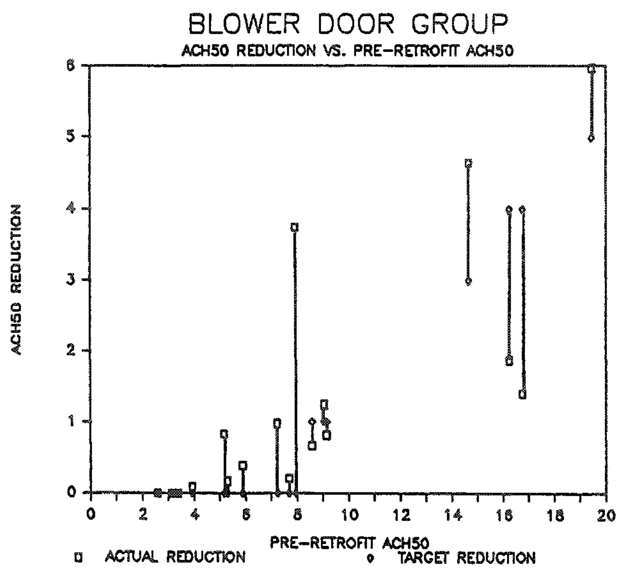

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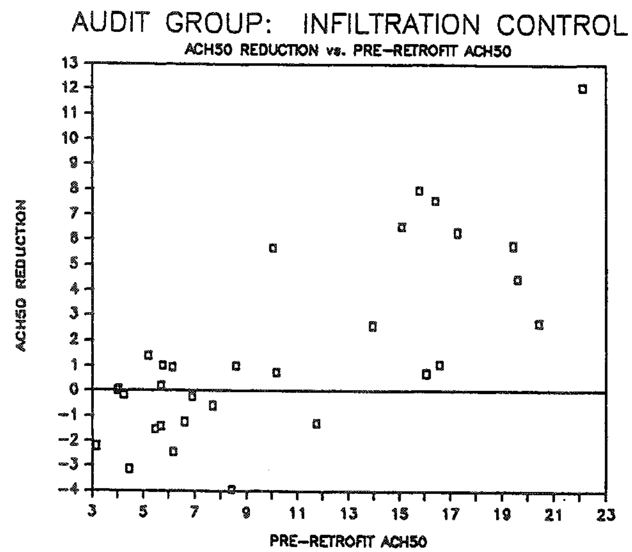

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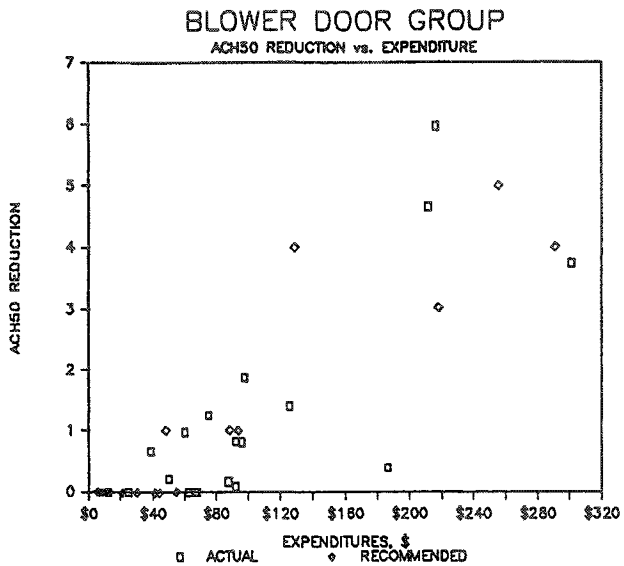

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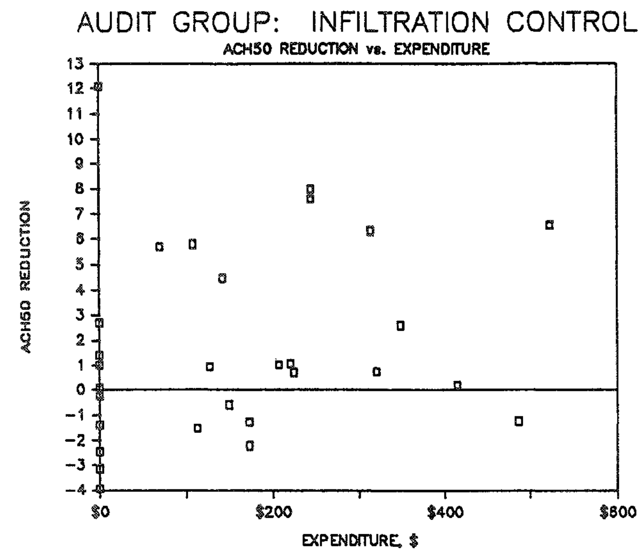

FIGURE 8

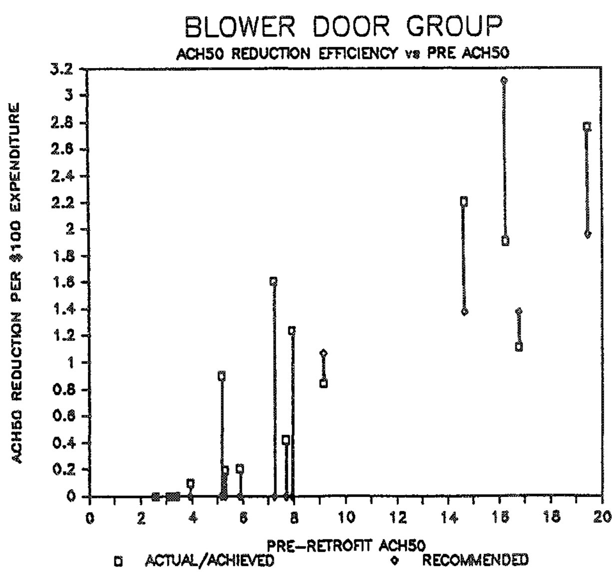

FIGURE 9